Modelling rainfall erosivity for dynamic hillslope erosion estimation in events of wildland fires, snowmelt, and extreme rainfall

Submitted by

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Certificate of original authorship

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis. This research is supported by the Australian Government Research Training Program.

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Contents

List of figures

List of tables

Summary

Rainfall erosivity and hillslope erosion are being significantly affected by frequent extreme weather events and ongoing climate change. Projected warmer climate in Australia will comprehensively change the erosion rates through more intensive storm events, more severe and frequent wildfire and less snowmelt. Moreover, Australian rainfall is dominated by high seasonal and interannual variability for current and also future climate, which was believed to increase the hillslope erosion and accelerate the land degradation through the high variation of rainfall erosivity. Changes in rainfall amount that have significant effects on rainfall erosivity and hillslope erosion in Australia have been well-studied, however, the impacts from extreme weather events, such as wildfire, storm events and snowmelt are not well quantified and rarely monitored. To estimate the near real-time rainfall erosivity and erosion change, it is essential to link extreme weather events with hillslope erosion model in response to the needs of effective ecosystem and environment management. The output of this research will assist with government decision-making of soil and land management, and more importantly, in adapting to changing climate and extreme weather.

In my research, I selected two case study areas in southeast Australia to assess the effect of extreme weather events on hillslope erosion through the dynamic rainfall erosivity factor. I chose Warrumbungle National Park (WNP) for the case study of near real-time estimation of rainfall erosivity because of an intensive storm event after a catastrophic wildfire in 2013. I chose New South Wales (NSW) and Australian Capital Territory (ACT) Alpine region, covering the Snowy Mountains, to project and assess the impacts of extreme rainfall and snowmelt on rainfall erosivity and the spatial and temporal changes.

Wildfire removes the soil cover and results in in insufficient cover to protect soils, which potentially opens a window for an extreme erosive event (e.g. storm). Hence, understanding the spatial distribution and temporal variation of wildfires and erosive rainfall events are highly important. I used the radar rainfall data (1km, 10-min), calibrated by rain gauges rainfall, to estimate the near real-time rainfall erosivity on a daily basis. I used the latest satellite-derived fractional vegetation cover (500m, Version 3.1.0), LiDAR DEM (5m and 10m) data and soil digital mapping along with radar-based rainfall erosivity to model the post-erosion by using Revised Universal Soil Loss Equation (RUSLE). I found that there was a positive correlation between radar-based and gauged rainfall (R^2 = 0.75, E_c = 0.66). The highest rainfall erosivity was estimated as 826.76 MJ mm ha^{-1} hr^{-1} for a single storm event. The modelled average annual rate of hillslope erosion since May 2014 was 1.35 t ha^{-1} yr^{-1}; and appears to be declining due to the vegetation recovery after the wildfire. There is strong seasonal and spatial variation of post-fire erosion, which is mostly driven by rainfall erosivity and the fire severity.

Six extreme rainfall indices (ERIs) derived from the NSW and ACT Regional Climate Modelling (NARCliM) Project (Evans et al., 2016) were selected to assess the extreme rainfall impact on rainfall erosivity for the baseline (1990-2009), near future (2020-2039) and far future (2060-2079). I used twelve ensembles (four Global Climate Models and three Regional Climate Models) and bias-correction rainfall data from NARCliM to estimate the future rainfall erosivity. I found that there was a strong positive correlation between the maximum 5-day accumulated precipitation (Rx5day) and the rainfall erosivity estimated from the NARCliM projections. In comparison with the result from Australia Bureau of Meteorology (BoM) in the baseline period, it is possible to estimate the approximately erosivity value (R^2 = 0.813, E_c = 0.74) from ERIs (e.g. Rx5day) especially to where without radar or gauged rainfall data.

Snow and temperature projections for the 60 years derived from NARCliM were applied to adjust the snowmelt runoff (Bormann et al., 2014) and rainfall erosivity model during the melting season (September, October and November) across the NSW and ACT Alpine region. Weekly measurements of snow depth and snow water equivalent at three filed sites in the Snowy Mountains were obtained from Snowy Hydro Ltd to assess the snowmelt-adjusted rainfall erosivity model. In addition, the NSW soil property projections were obtained from OEH (Gray et al., 2017) and used to calculate soil erodibility based on Yang et al. (2017). Other input data, such as a 30 m DEM, and the latest satellite-derived fractional vegetation cover (500m, Version 3.1.0) at a monthly time-step since 2000 (Guerschman et al., 2009) were used along with the snowmelt-adjusted rainfall erosivity to model the hillslope erosion by using RUSLE in the Alpine region. I found that the snowmelt in spring is estimated to increase the rainfall erosivity by about 12.95% in the baseline period compared to the results without snowmelt adjustment. However, the snow impact is projected to be 24.84% for the near future and then less (1.63%) for the far future due to the projected higher temperatures and less snow depth, using NARCliM simulations. The highest erosion risk area within the study area is projected to be 19.95 t ha^{-1} yr^{-1} in South East and Tablelands (SET). ACT has the highest average erosion rate (0.37 t ha^{-1} yr^{-1}). Despite higher rainfall erosivity in the NSW and ACT Alpine region, the corresponding hillslope erosion is projected to be less than in the ACT since the soil erodibility and groundcover factor area relatively low.

This research assessed the impact of extreme weather events on rainfall erosivity and hillslope erosion in selected study areas in southeast Australia. The erosion amount and changes under climate change do not simply result from a single factor, but are comprehensively derived from various factors, including rainfall erosivity, groundcover, slope length and steepness and soil erodibility. These factors always combine and interact to influence and accelerate the mechanism of the erosion process under more frequent and more extreme weather events. The current outcomes would effectively enhance the capability of policy marker, and provide adaptation and mitigation strategies in responding to wildland fires and a changing climate. Automated Geographic Information System (GIS) scripts have been developed to calculate the time-series rainfall erosivity and hillslope erosion, so that the processes of large quantity data are realistic, repeatable and portable.

The proposed outline for this thesis is as follows:

Chapter 1: Introduction

Chapter 2: Estimation of storm event-based rainfall erosivity from weather radar data in burnt area

Chapter 3: Modelling and monitoring post-fire erosion across Warrumbungle National Park

Chapter 4: Extreme rainfall indices and its impact on rainfall erosivity under climate change

Chapter 5: Rainfall erosivity, hillslope erosion and the spatial-temporal variability across Australian Alpine region

Chapter 6: Final conclusion and future direction